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A Perspective on Research Opportunities in Manufacturing Flexibility

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Our interest in manufacturing flexibility stems from the fact that the use of flexible resources is often the most appropriate and cost effective response mechanism in dealing with global competition, rapidly changing technology, and shorter product life cycles. Leveraging flexibility becomes a key issue as many managers and organizations are driven to achieve more with less. But how can that be done? How can flexibility be measured? What are the main drivers that lead to organizations becoming more flexible and profitable? The questions are plentiful, but succinct answers are harder to come by. One reason for this difficulty is that even though progress has been made, the concept of flexibility is not well comprehended in its entirety. The collective understanding of managers and academics of this complex concept is limited. However, we believe that opportunities exist for academics to learn more about manufacturing flexibility from practicing managers in the industry, and in turn contribute insights to them through our own research.

Before we further our discussion, it will be useful to briefly review and summarize the existing knowledge in this domain. Manufacturing flexibility has been defined as "the ability to change or react with little penalty in time, effort, cost or performance" (Upton 1994, p. 73). It is widely recognized as a multi-dimensional concept (e.g., Hyun & Ahn, 1992; Gerwin, 1993; Sethi & Sethi, 1990; Upton 1994). For example, machine flexibility, labor flexibility, and routing flexibility all contribute to manufacturing flexibility. Flexibility is influenced by management practices and operating policies, and hence must be planned for and managed.

As such, there are many different perspectives from which flexibility can be viewed. It can be either reactive or proactive in nature. The reactive nature of flexibility addresses both internal as well as external environmental uncertainty faced by an organization (Slack, 1983). Its proactive nature allows an organization to "redefine market uncertainties" or influence what "customers have come to expect from a particular industry" (Gerwin 1993, pp. 396, 397). Flexibility can also refer to the potential versus actual flexibility of an organization. Potential flexibility is the degree of flexibility which managers or operators believe the system or resource could achieve. In contrast, actual flexibility reflects the degree of flexibility which a resource, plant, or organization is currently achieving. Finally, flexibility is a relative attribute, as opposed to an absolute one (Tidd, 1991). It is always examined with respect to a set of alternatives to assess its magnitude.

So where do we start focusing our research efforts? It is not that the issue of manufacturing flexibility has not been addressed in prior research. Much of the earlier work in the 1970's and 1980's was modeling oriented, and provided the basis for our initial understanding of this concept. Over time, realization set in that complexity

arises from the fact that manufacturing flexibility has many different facets. Researchers took limited cuts at addressing these different facets, with the limitation that the existing research tools were not amenable to evaluating all of them simultaneously. In response, several researchers published conceptual as well as empirical studies that attempted to overcome these past limitations. Other empirical studies on flexibility sought to compare plants with competitors in the same industry (e.g., Jaikumar, 1986; Dixon, 1992; Suarez et al. 1995, 1996; and Upton 1995, 1997).

While progress has clearly been made, much remains to be done. Unfortunately, good operational measures that span multiple industries do not exist, which in turn has hindered efforts to increase our understanding of flexibility (Gerwin, 1993; De Toni & Tonchia, 1998). Such measures could provide a necessary and consistent means of making comparisons across studies and industries. In addition, relationships between flexibility and other decision areas of the organization could be more fully explored. We believe that creating valid, robust, and generalizable measures for different facets or dimensions of manufacturing flexibility is the most important missing link in furthering our understanding and cumulative knowledge of this area.

Our own research work has taken small steps in that direction. Using the conceptual, modeling, and empirical work of prior authors, we have tried to build a theoretical foundation for the measurement of manufacturing flexibility (see Koste & Malhotra, 1999). The initial step of Churchill's (1979) widely accepted paradigm calls for the definition of the construct to be measured. We have addressed this need, providing definitions for ten manufacturing flexibility dimensions. While these definitions lay the necessary groundwork, additional work is needed to complete the remainder of the procedure. We have started collecting and analyzing empirical data from diverse industry groups in order to build psychometrically sound scales for six of these flexibility dimensions. Additional studies may be needed to further refine and validate these measures in additional contexts. Once these measures are fully developed and widely accepted, there are a number of research avenues that could be addressed.

Flexibility Hierarchy

The relationships, if any, that exist between different dimensions of flexibility merit further exploration. For example, supportive relationships have been proposed between different dimensions of flexibility. These relationships are often captured in flexibility hierarchies (e.g., Koste & Malhotra, 1999; Sethi & Sethi, 1990; Hyun & Ahn, 1992). These hierarchies identify those flexibility dimensions that serve as building blocks for the development of other, higher level flexibility dimensions. Unfortunately, there is only a limited agreement between the various hierarchies, and the proposed relationships are largely untested. Further examination is warranted to determine the strength and nature of these relationships. Minimum levels of flexibility needed for the building block dimensions should also be ascertained, so that precious resources are well allocated between developing dimensions across the hierarchy. Within this context, trade-offs or interactions that may exist between flexibility dimensions at the same hierarchical level need to be better understood.

It is possible that significant synergy may exist between different dimensions of flexibility. Organizations may realize considerable benefits by concurrently developing several higher-level flexibility types (such as new product flexibility and mix flexibility), instead of focusing on one flexibility dimension at a time. Research that explores these issues would greatly enhance our understanding of how flexibility must be developed in organizations.

Flexibility and Strategy

Researchers should examine the relationship between strategy development and flexibility development. An organization with multiple plants may utilize a single corporate strategy to manage them as a whole, or a plant may develop its own individual strategy for long term decisions. These are two radically different approaches, even though it is well recognized that the manufacturing strategy of the plant should be consistent with the corporate strategy and should identify those competitive priorities on which it will compete (Hayes & Wheelwright, 1984). Both the process of formulating strategy, as well as the resulting content, is important. Thus flexibility issues must be examined for process and content components of strategy, while clearly recognizing the differences between corporate and manufacturing strategy. We propose a two-by-two framework below in Table 1, which contains a sample of the research issues that warrant further investigation.

Formulation of the corporate strategy should take into consideration the business environment and the capabilities of the organization. The presence of effective, generalizable measures for flexibility would facilitate an examination of the degree of alignment between flexibility and the business environment. The extent of alignment and the resulting organizational performance could then provide some interesting insights. Alternatively, the impact on flexibility of certain organizational variables, such as organizational culture and locus of decision making, could be examined to see which ones are more conducive to flexibility development.

The content of the corporate strategy should also be examined in order to determine those flexibility dimensions that support different generic strategies. The typology of either Porter (1985) or Miles and Snow (1978) could be examined in this manner. The performance of corporations that coordinate or network flexibility capabilities across multiple plants could be evaluated to test alternative hypothesis. For instance, it is possible that performance across a group of plants can be enhanced by having each plant excel at only a limited number of flexibility dimensions instead of attempting to master many types. This approach, of course, is only viable if the group of plants, as a whole, provides the necessary flexibility capability for the entire organization. But we do not know whether or how such an approach can be pursued in practice.

The characteristics of manufacturing strategy-planning process, such as the degree of formality or the involvement level of managers, may impact the level of flexibility. The extent and direction of this impact, however, is unknown. Yet another research opportunity exists with respect to the proactiveness of manufacturing managers. The pattern of structural investment decisions undertaken by manufacturing

Strategic Level	Components of Strategy: Process	Components of Strategy: Content
Corporate Strategy	Degree of alignment between flexibility capability and the business environment and its impact on performance.	Flexibility dimensions that are associated with generic low cost or differentiation strategies.
	Impact of organizational variables (centralized vs. decentralized decision making, organizational culture, etc.) on the level of flexibility.	Networking of plants with different flexibility capabilities and its impact on performance.
Manufacturing Strategy	Relationship between manufacturing, strategy planning characteristics (formality, involvement, etc.) and the level of flexibility.	Trade-offs between flexibility dimensions and other competitive priorities.
	Impact of structural investment patterns (proactiveness) on flexibility.	Competitive positioning of the firm with respect to flexibility.

Table 1. Strategic research issues.

managers could potentially enhance or limit flexibility in the plant. Clearly, the effect of these issues on flexibility merits further research.

The content, or task, of the manufacturing strategy should also be examined with respect to flexibility. For example, trade-offs may exist between different dimensions of flexibility or between flexibility dimensions and other competitive priorities (Skinner, 1969, 1996). The identification and analysis of any such trade-offs would certainly aid managerial decision making with respect to emphasizing a given set of competitive priorities.

While this discussion is not exhaustive, it is clear that a number of research opportunities exist with respect to flexibility and strategy. These opportunities can be undertaken following the development of generalizable measures for flexibility.

Flexibility and the Product-Process Matrix

The study of interaction between flexibility and the product-process matrix provides additional research opportunities. Hayes and Wheelwright (1984) suggest that firms will be positioned primarily along the diagonal, from the upper left to the bottom right of the matrix. Recent empirical research by Safizadeh et al. (1996) largely supports this notion, although a number of off-diagonal firms were identified. Perhaps flexibility allows these off-diagonal firms to overcome any performance consequences that would otherwise be associated with such a positioning. If so, the types and implementation level of these flexibility dimensions need to be identified. Such an analysis would provide insights into the flexibility requirements of operating successfully in such off-diagonal positions.

Insight into flexibility can also be gained by examining those firms that occupy positions on the diagonal of the product-process matrix. Flexibility dimensions that are emphasized in job or batch shops are likely to differ from those emphasized in production line or continuous flow environments. However, this assertion needs to be tested and the extent of any differences evaluated. Such an effort could lead to a mapping of flexibility dimensions with process choice.

Flexibility and Supply Chain Management

The presence or absence of flexibility in supply chains, and its relationship with performance, should also be explored. Supply chain structures can range from segmented, with minimal interaction among the supply chain members, to integrated, with extensive interaction among the supply chain partners (Krajewski & Ritzman, 1998). The effect of such integration on the development of flexibility in the supply chain should be examined. In addition, the competitive priorities of the supply chain may impact flexibility. Efficient supply chains may emphasize certain flexibility dimensions, while responsive supply chains focus on others. An understanding of these differences, if any, would enhance the management of such supply chains.

Cost/Benefit Analysis

Investments in flexible technology can be difficult to evaluate (e.g., Andreou, 1990; Ramasesh & Jayakumar, 1993). In addition, flexible technology is generally more costly than non-flexible technology (Gaimon & Singhal, 1992; Fine & Li, 1988). Without a means of effectively quantifying flexibility, such investments may not be undertaken. However, if the flexibility provided by various investment options could be more accurately assessed, it would be easy to perform a cost/benefit analysis. The explicit gains in flexibility provided by one technology over another (e.g., FMS or a job shop) could be quantitatively compared to the cost differential, and market implications assessed.

Flexibility improvement efforts within manufacturing organizations could also be quantitatively evaluated prior to undertaking

them. The resource requirements of the improvement efforts could be compared to the potential benefits. Benefits could be internally realized, such as reduced inventory levels, or externally visible, such as reduced lead times or broader product lines. These comparisons, in conjunction with qualitative considerations, would enhance managerial decision making about improvement initiatives.

Field Studies

It would also be interesting to trace longitudinally over time the development of flexibility in different organizations. Just as there are many different ways to become world class manufacturers, there may be many different approaches to becoming flexible. Field studies that undertake long-term, in-depth analysis of a selected set of organizations could provide valuable insights. These field studies could also produce some excellent benchmarking comparisons for those organizations that are striving to become more flexible. Organizations that demonstrate "best practice" on a given flexibility dimension may serve as training grounds for others. The potential benefits of such field studies to our understanding of flexibility could be tremendous.

This is a limited sample of those studies that would be possible if valid, reliable, generalizable measures of flexibility were developed. Clearly, considerable work remains to be done before the concept of flexibility can be understood in its entirety. We offered our thoughts here with the objective of spurring additional debate and discussion, along with creating a forum in which other researchers could contribute their own insights into these issues. While we believe that the starting point of research projects in this area for the time being should be the measurement of manufacturing flexibility, others in the field could build upon these measurement studies to further refine the measures and test alternative theories and research directions outlined here. Hopefully, efforts of several groups of researchers would eventually converge to create a holistic perspective of this complex concept.

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